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Assessment of storage options for reduction of yield losses in a region with 100% renewable electricity

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Abstract

In the federal state Schleswig-Holstein (SH) the installed capacity of distributed generation has been growing faster than the transport capacity of power networks. Currently, this causes network congestions and requires corrective measures as curtailment. In 2012, around 3.5% of renewable generation in SH was curtailed. As one possible option for reducing these yield losses energy storage has been suggested. In a project for the state government of SH Ecofys and Fraunhofer IWES investigated potential benefits of storage technologies in electricity networks in this region. The analysis was carried out separately for the transmission and distribution levels.
Based on hourly simulations of future renewable generation and load time series of a 2025 scenario, congestion effects on the transmission grid level were evaluated by using residual load analysis. By matching situations of negative residual load against current and future transfer capacities in SH it becomes obvious, that an appreciable amount of surplus situations for a potential utilization of energy storage only occurs with current transfer capacities. It diminishes with the planned expansion of transmission grid.
On distribution grid level, Ecofys assessed the characteristics of curtailment applied during recent years with detailed empirical data. The analysis of congestion management actions showed that the storage's cycling intensity related to curtailment will be low whereas power intensity is potentially high.
The economic benefits of reducing RES-E losses do not offset the costs of storage. Hence, application of storage for reducing curtailment losses is viably only if part of the investment costs are socialised in one way or another.
Finally, the paper identifies a number of arguments supporting the development of storage technologies and describes key framework conditions which could be changed to support storage projects.

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1. Introduction

In many regions of Germany, as in other parts of the world, installed capacity of renewable energy sources providing electricity (RES-E) has been growing faster than the transport capacity of distribution and transport networks. As illustrated in Figure 1. this causes network congestion which requires corrective, operational measures in order to avoid overloading network assets. Recently, curtailment of distributed generation can be witnessed more and more regularly. Depending on the region, system operators apply curtailment requests as often as thousands of times a year. In total, up to 550 GWh or 0.4% of the RES power generation needed to be curtailed in 2013 in Germany. [1,2,3]

Of course, curtailment causes yield losses. From a plant operator's as well as from a societal perspective, curtailment volumes should be minimized. As one alternative option, energy storage connected to distribution networks has been suggested for reducing these yield losses. In times of high RES-E generation, energy storage allows surplus electricity causing congestions to be stored. Later, when the congested network situation relaxes, the stored electricity can be released and transmitted to the customers.

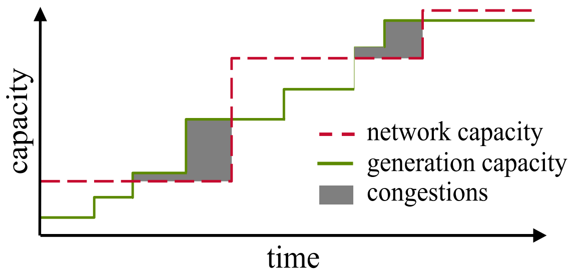


Fig. 1. Schematic comparison of the development of network capacity and the installed capacity of RES-E. Source: Ecofys

The northern German federal state Schleswig-Holstein (S-H) represents a region with a high share of RES-E, nearly 100 % by 2014. In comparison to the total share of RES-E 27 % in Germany, certain effects of a high penetration can be observed much earlier in Schleswig-Holstein. Therefore, in 2012 around 70 % of the curtailed energy in Germany was in Schleswig-Holstein. Between 2 and 3 % of the RES power generation in this region was curtailed. [3,4,5]

For this particular region, Fraunhofer IWES and Ecofys have assessed the characteristics of network congestions in S-H during the last years with a high resolution of empirical data in dimensions of space and time [6]. Based on this analysis we evaluated potential benefits of distribution network connected energy storage in order to reduce the yield losses in the period until 2022 in Schleswig-Holstein. Furthermore, an analysis of transmission network congestions was conducted for a 2025 scenario in order to evaluate possible benefits of new power storage.

Based on the detailed analysis in [6], we present an overview of the analysis and results in the following structure: section II presents a general description of the distribution grid in Schleswig-Holstein; section III describes the applied methodology; in section IV and V we describe and analyse the classification in temporary and permanent network congestions; section VI analyses power storage from the transmission network point of view, and section VII presents general conclusions.

2. Description of transmission and distribution network in Schleswig-Holstein

The power system in Schleswig-Holstein is characterized by three major network operators which are allocated in different voltage levels:

- TenneT TSO GmbH (>110 kV),
- E.ON Netz GmbH (110 kV) and
- Schleswig-Holstein Netz AG (<110 kV).

In Schleswig-Holstein the total installed capacity of RES-E is 5.2 GW, which represents about 7% of the installed capacity in Germany. In 2013 80 % of the total RE-installations in Schleswig-Holstein was installed in the distribution grid of the Schleswig-Holstein Netz AG (S-H Netz AG). Due to the high share of wind power in their network, around 80% of the distributed generation is connected to the medium voltage level [7]. Figure 2. gives an overview of the allocation of RES-E in Schleswig-Holstein.The three listed major network operators frequently perform congestion management actions due to network congestions. Predominantly, S-H Netz AG curtails the distributed power units, because most units are connected to their network. The majority of curtailment is linked to wind power units. [3,8,9]

A current study [5] predicts further, significant growth of RES-E, especially for wind power, in Schleswig-Holstein. The local government estimates [13] that the installed capacity of wind energy will triple and reach 9 GW by 2020. In addition, more than 2 GW of wind offshore will be connected to the transmission grid by 2020. Due to the combination of the dynamic development of RES-E and the delays in grid extension [3], remaining network congestions can be expected in the coming years.

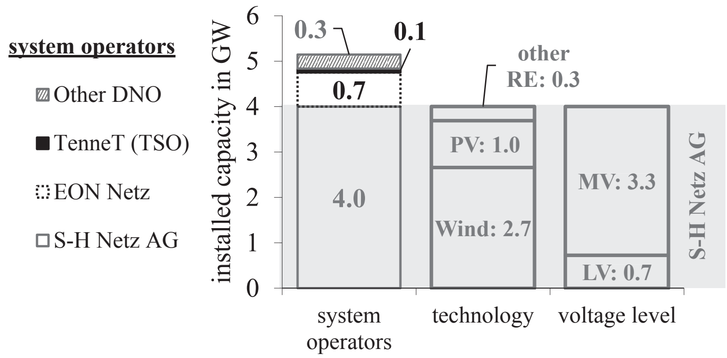


Fig. 2. Overview of the RES-E dispersion in Schleswig-Holstein in 2012. Source: Ecofys based on [7]

3. Methodology

In this section the generic approach used to assess the benefits of energy storage by reducing yield losses and the amount of congestion management actions is presented. In general, the study is separated according to the examined system levels, the distribution (section IV and V) and the transmission grid level (section VI).

For the analysis in the distribution grid level, three main steps can be identified: 3.1: network congestions are classified to identify possible energy storage applications; 3.2: operational requirements for energy storage are characterised in order to define the specific use case; 3.3: economic benefits of energy storage are assessed.

As input for our analysis, we prepared the following data sets which are based on publicly available data.

- The Ecofys-curtailment database. This database consists of all published congestion management actions by the German system operators between 2009 and 2013. All records are standardised and linked to affected distributed power units and substations. [9,10]
- Register of renewable power units from the German system operators according to the German Renewable Energy Act. This database includes specific information of each power unit, like installed capacity, date of installation, region, voltage level, etc. [7]
- Empirical grid data of S-H Netz AG, like residual load flow, feed-in, losses, etc.. The records have a time resolution of 15 minutes and are allocated to a specific voltage level. [11]
- Geographical data of the network development plan of S-H Netz AG, including appropriate wind areas, areas of wind parks, substations, lines, estimated regions of congestion management actions, etc. [12]

In order to address the congestion situation and the resulting potential of energy storage on the transmission grid level, we analysed the residual load for a scenario year 2025 in S-H. The residual load profile is obtained by subtracting simulated renewable feed-in time-series (wind on-/offshore, photovoltaics and biomass) with a high spatial and temporal resolution from the demand profile. In a next step, the resulting hourly residual load profile is compared against S-H's current and also future exchange transfer capacities with adjacent federal states in Germany and neighbouring countries. As the domestic and cross-border exchange is a result of scheduling decisions in the respective market areas, which were not within the scope of the study, we drew on import and export schedule results from a European unit commitment simulation and load flow calculations based on the dena grid regions which had been earlier conducted for an almost identical scenario at Fraunhofer IWES.

As for the congestion analysis on the transmission grid level, we employed the following data sets that are in detail described in [6]:

- Renewable generation capacity for scenario year 2025 in S-H were based on a recent study conducted by Pöyry [5] and interviews with the Ministry for Energy and Environment in S-H (MELUR),
- Spatial development data for the placement of onshore wind generators [23],
- Electricity demand profile based on historical time-series provided by ENTSO-E [22] for Germany, which is scaled to the combined electricity demand of S-H and Hamburg (HH) according to the German grid development plan [25],
- Current transmission grid data based on [24], future grid development assumptions based on [25].

3.1. Classification

Basically, as illustrated in Figure 3. network congestions in the distribution system can be separated into two types. These types lead to different reasons for employing energy storage.

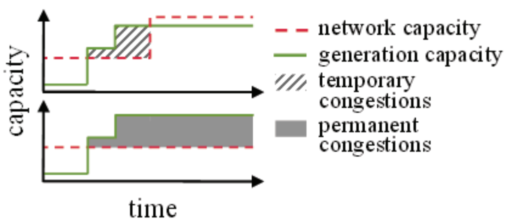


Fig. 3. Schematic comparison of temporary and permanent network congestions. Source: Ecofys

1) Temporary network congestions: At the distribution system level, congestion has historically been dealt with by planned upgrades of distribution system components. Such upgrades, however, cannot follow the pace of

the rapid generation developments of RES-E in the distribution networks and therefore lead to temporary congestions. During this transitional period energy storage has the potential to reduce yield losses.

As curtailment actions due to temporary network congestions were published, we combined the empirical data of congestions and residual load flows of the S-H Netz AG to analyse historical congestions for selected substations on a temporal and spatial scale. In addition, we evaluated the available data on the network development of S-H Netz AG to estimate the future development of temporary network congestions until 2022. Based on the results we identified possible applications for energy storage in the distribution grid to reduce yield losses. Furthermore we identified suitable storage technologies.

2) Permanent network congestions: Currently, it is being discussed whether or not a network design, which integrates very seldom peaks of generation by variable renewable energy sources, is an optimal solution. Instead of grid extension, additional and permanent technical options, like energy storage, may be more efficient to avoid congestions. Therefore an optimal network design needs to be defined, which however mainly is a political question.

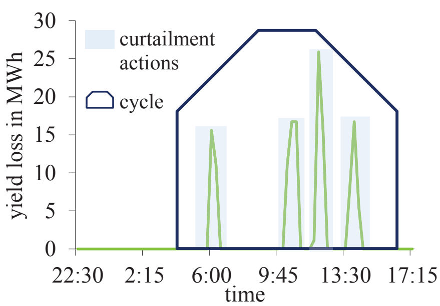
As permanent congestions have not yet occurred in Germany, our classification was based on modelling results of recent studies [14,15,16].

3.2. Characterisation

For the identified applications, we characterised the operational requirements of energy storage systems on the basis of three attributes. Therefore, we described the specific use case for storage to reduce the yield losses.

Operational cycles: A crucial criterion to design an energy storage system is to define the scope of an operational cycle. This directly influences the level of utilisation. As the records consist of many several consecutive curtailment actions and the discharge of the storage requires sufficient network capacity for a long period, we aggregated several actions to one cycle. Figure 4. presents a schematic overview of this method. Based on the calculation of the cycles we quantified the level of utilisation.

Fig. 4. Schematic description of the aggregation of curtailment actions to define a cycle. Source: Ecofys



- Duration of utilisation: In addition to the number of operational cycles, the potential load time is a second relevant criterion to dimension the storage for the specific use case. In this context we used the period of the curtailment actions as a simple, but reasonable approximation to determine the duration of utilisation.
- Power conversion: The third criterion used to specify the needed power conversion rate of the storage system affecting the design of the power capacity. The calculation was based on the estimated maximal power flows at the investigated substations during congestion management actions

3.3. Economic assessment

In addition to the estimated technical potential of using energy storage to reduce the amount of curtailment, we calculated the generation costs for different technologies and compared them with respective economic benefits.

To reflect strong uncertainties of the development of recent storage technology until 2022, we added a sensitivity analysis reflecting various cost scenarios. In the last step, we discussed the potential impact of combining multiple management concepts.

4. Temporary network congestions onthe distribution grid level

According to the current regulation §12 EEG 2014, German system operators are obliged to extend their network if the network capacity reaches its limits. When that is the case, network congestions are of temporary nature. In order to estimate the related potential demand for storage, we analysed specific congestions in the distribution network in Schleswig-Holstein in the following paragraphs.

4.1. Classification in space

Classifying the occurred congestions, we compared load flows during the congestion management actions and cumulated duration of curtailment actions in different substations. The main results can be summarized as follows:
Distribution network congestions

- differ in volume and intensity and
- occur in various network situations.

Therefore the storage needs to be designed for the specific characteristic of the network congestions in the individual region, which depend on criteria like

- network capacity,
- load distribution / behaviour,
- structure of the RES-E population,
- wind load factor or
- specific structure of the grid.

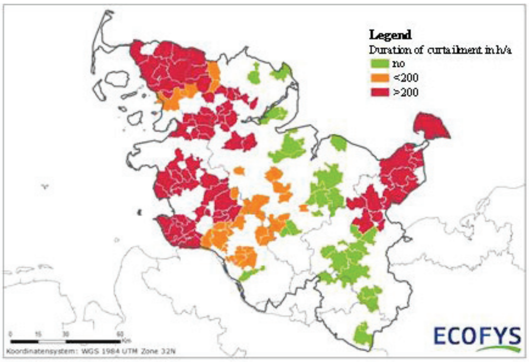


Fig. 5. Overview of the intensity of curtailment actions in Schleswig-Holstein in 2013. Source: Ecofys based on own calculations and [12].

4.2. Classification in time

Through an evaluation of the network development plan of S-H Netz AG [12], we classified the development of network congestions in time. Basically, network congestions are caused due to the resulting gap of a divergent development between the network capacity and RES-E capacity. As a result of our analysis, Figure 6. reflects the discrete forecast of the resulting limitations on feed-in in 2022.

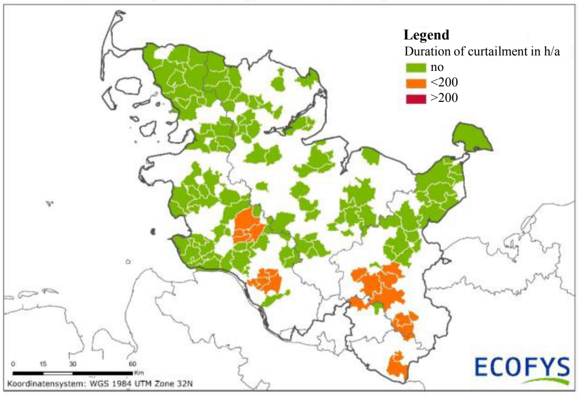


Fig. 6. Overview of the intensity of curtailment actions in Schleswig-Holstein in 2022. Source: Ecofys based on own calculations and [12].

Based on a more detailed examination for the years in between, the following findings can be highlighted. The intensity of network congestions in the distribution network

- are fluctuating in certain regions in time and
- develop differently in various regions over time.

Regarding these results and taking into account that most energy systems have a lifetime of 5 to 30 years [6], the conditions for energy storage systems to reduce yield losses are changing over their lifetimes. Therefore the systems should be

- modular,
- adjustable in their capacity and
- semi-mobile.

At the moment only electrochemical energy storage systems, like batteries, comply with these requirements. That is why we focus on these technologies in the following sections.

4.3. Level of utilization

The number of operational cycles, in which the storage can be charged and fully discharged again, is a relevant parameter when designing a battery system. Based on this parameter the level of utilisation and the technical lifetime of a battery can be estimated. In general, a high level of utilisation increases the economic viability, but a high number of cycles decrease the technical lifetime.
Because curtailment actions appear in short sequences, we synthesised a set of sequential actions into one cycle, as described in section III.B. The duration between two cycles is at least 24 hours, as we assumed that the network

capacity will be satisfactory to discharge the storage, if no curtailment action occurs for this period. With this assumption 1,900 curtailment actions represent 500 cycles. Varying the chosen interval between two cycles in the magnitude of several hours shows, that the results are robust, as the duration between most records is short.

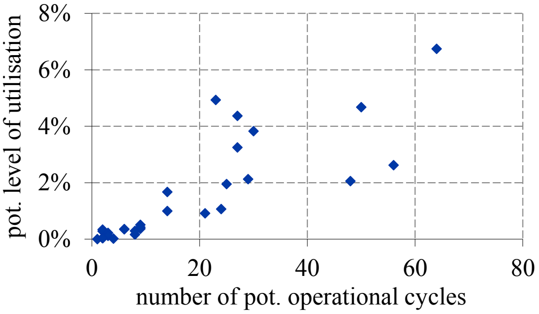


Fig. 7. Overview on potential level of utilisation and number of operational cycles for individual substations in Schleswig-Holstein in 2012. Source: Ecofys

Figure 7. presents the potential level of utilisation and the number of operational cycles for each investigated substation. As clearly indicated, exploitable events seldom appear as they do not exceed one hundred events per year and occur at a few substations. In addition, the level of utilisation in one year is considerably below 10 %.

4.4. Duration of utilization

As a second important element in the design process of the battery system, information on the charge time is needed. For this purpose we examined the distribution of the duration of all inventoried records in several years. The exemplary graph for 2012 in Figure 8. shows a strong variance in the duration, but a significant accumulation of records with a really short period. The specific characteristic of this graph is comparable for different years and individual substations. To store as much yield loss as possible and being appropriate for variable charge times, the storage needs to be rigorously oversized. Otherwise, an optimization of the load duration would lead to less potential use of curtailed energy.

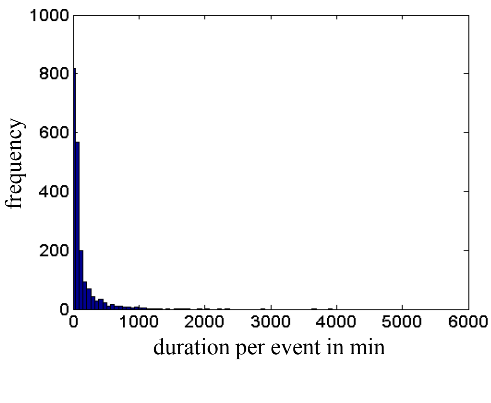


Fig. 8. Histogram of the duration of curtailment actions in Schleswig-Holstein in 2012. Source: Ecofys

4.5. Power capacity

Based on the Ecofys-curtailment database, we estimated the curtailed power for individual substations. This value reflects the required load power of the battery avoiding curtailment. In addition, we evaluated the duration between two cycles in order to estimate the potential generation power of the storage. In conclusion, the estimated power transfer is characterised as power-intensive, particularly in the charging process, due to the short duration of curtailment action. At least for electrochemical energy storage systems, the load power is the relevant criterion when designing the used battery system.

4.6. Economic benefits

By assessing the economic benefits of energy storage in reducing yield losses, we consider the following assumption:

- The focus is laid on electrochemical energy storage systems (PbSO4, Li-Ion, NaS, Redox-Flow) as they provide a good fit to the identified applications (modular, adjustable in their capacity and semi-mobil)
- Relevant technical parameters for 2012 until 2022 are based on [6]
- Battery is designed for a region with a high congestion intensity (number of operational cycles is 100)
- Accrued energy can be stored with procurement costs of 0 EUR/MWh

In the next step we calculated the specific annual amount of depreciation (EUR/kWh) and the resulting power generation costs (EUR/MWh) for different technologies.

Table 1. Economic figures for 2012.

technology	specific annual amount of depreciation (EUR/kWh)	generation cost (EUR/MWh)
PbSO4	60	800
Li-Ion	130	1,500
NaS	110	1,400
Redox-Flow	90	1,400

When comparing the figures from TABLE I. with the current feed-in tariff in Germany of less than 100 EUR/MWh [17] or the market value of wind energy of less than 40 EUR/MWh [18], the stored energy costs about 10 times more. In general, the high generation costs are mainly caused by the low number of operational cycles. Regarding the chosen assumptions and their positive influence on the economic figures, the calculation describes a quite optimistic scenario. In conclusion, for this specific application batteries cannot be operated profitably.

In the next step, we did a sensitivity analysis to reflect possible developments of technology costs until 2022. Based on different scenarios in [6] the generation costs for PbSO4 varies between 400 and 1,800 EUR/MWh. Even, in a strongly progressive scenario the profit margin for this single application is negative.

As a single application cannot reach a positive margin, the combination of various operating concepts for energy storage systems may improve the cost-effectiveness. First of all, reserve power markets promise significant higher specific revenues per MWh, but in principle, possible combinations should be assessed first to determine if they are technically feasible and compliant with regulations. Especially the combination of reserve control and congestion management is determined by strong technical conflicts.

5. Permanent network congestions on the distribution grid level

At the moment it is being discussed whether or not a network design, which integrates very seldom generation peaks by variable renewable energy sources, is an optimal solution from an economical perspective. Recent studies [14,15,16] show, that intentional peak shaving of variable renewable energy sources could significantly reduce the needed grid extension by the network operator. The authors estimate that at maximum 2 to 5 % of curtailed renewable energy would reduce the cost for network extension by 15 to 50% [14,16].

Regarding these figures, we analysed whether or not the avoided investments could be used for energy storage. At present, in parts of Schleswig-Holstein, the amount of curtailed energy already reaches 5 %. In an optimistic scenario the cost for energy storage sums up to 340 million EUR per year, assuming a generation cost of 800 EUR/MWh. For this value, the 110 kV network could be extended by 300 to 700 km per year. For comparison, two examples are given:

- The network plan development initiative in Schleswig-Holstein identified a network extension of 230 to 370 km in the period between 2010 and 2015 [20].
- In the distribution network study from the German energy agency (dena) [21], the total costs for the full network extension between 2015 and 2030 in the low, medium and the 110 kV voltage level is estimated at 2 to 3 billion EUR. The cumulated cost for energy storage to reduce the network extension by 15 to 50% would be in the same magnitude.

Both examples clearly show that energy storage systems are not an efficient alternative for grid extension in order to avoid permanent network extension in the distribution system. Finally, additional case studies like [19] reveal, that an uncoordinated operation of energy storage may even increase the probability for network congestions.

6. Residual loadanalysis on the transmission grid level

As a first step for the evaluation of the energy storage potential in S-H on the transmission grid level, we determined the 2025 residual load profiles for five historical meteorological years, 2007 – 2011. In all of these reference years, negative residual loads occur in more than 5,000 hours of the year implying that the hourly renewable feed-in is higher than the hourly electricity demand in S-H and HH combined. The generation figures of the S-H scenario 2025 are shown in TABLE II. Also included is the generated energy for the 2025 scenario based on the historical meteorological year 2011 which reveals the most hours with negative residual load situations and therefore constitutes the basis for the comparison against exchange transfer capacities in the second step.

Table 2. Generation figures for the scenario year 2025 in S-H. Source: Fraunhofer IWES

Generation technology	Generation capacity 2025 (MW)	Generated energy 2025 (reference 2011) (GWh)
Onshore wind	9,630	27,743
Offshore wind	2,967	11,953
PV	2,944	2,892
Biomass	329	1,998

Depending on the assumed exchange transfer capacities between S-H and other domestic regions or neighbouring countries, negative residual load values can be categorized as either transferable or surplus power. Below, we considered two cases of exchange transfer capacities, the first encompassing the existing transmission grid capacities and the second also including transmission grid expansion projects according to the German grid development plan.

Because of its particular geographical situation, the transmission grid in S-H has to fulfil an energy transit function while at the same time integrating high shares of renewable energy. This is why import and export schedules with neighbouring countries have a significant impact on the analysis' results and cannot be neglected here. By incorporating the results of European unit commitment simulations previously conducted at Fraunhofer IWES, we identified a "North-South" load flow situation in 6,658 hours of the year. These "North-South" load flow situations can be characterized by pure energy import from interconnected northern market areas which has to be transported through S-H to the bordering domestic regions in the South. In these situations, the additional cross-border import of energy from the North yields even higher negative residual loads. The resulting residual load curve of these "North-South" load flow situations is plotted as a duration curve in Figure 9. The horizontal lines indicate the available exchange transfer capacity of S-H with its bordering regions within Germany.

Case 1: The blue line represents the transfer capacity of the existing transmission grid and leads to surplus situations in about 1,600 hours of the "North-South" load flow situations (surplus energy 2.7 TWh and maximum surplus load 5.1 GW). As this case compares today's transmission grid capacity against a future renewable scenario for the year 2025, it represents a very progressive estimate of surplus situations and therefore also of the potential for the application of energy storage.

Case 2: The green line depicts the exchange transfer capacity of the existing and additional transmission grid expansion projects. In this case there surplus situations do not exist anymore, because the higher exchange transfer capacity is sufficient to transport all negative residual loads to S-H's bordering regions in the South.

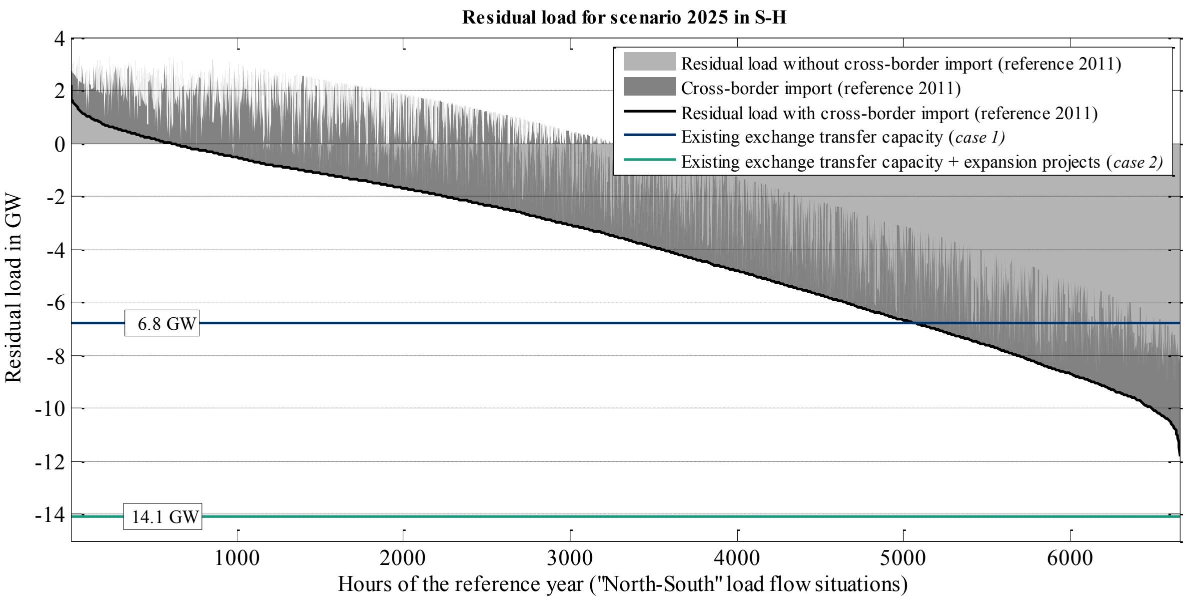


Fig. 9. Comparison of residual load duration curve in "North-South" load flow situations for the scenario 2025 in S-H and two exchange transfer capacity cases (existing and existing plus expansion projects). Source: Fraunhofer IWES

Depending on the realization and progress of grid expansion projects, regional surplus situations in S H will become fewer. Accounting for effective operational cycles with sufficient time to charge and discharge will lower the level of storage utilisation even more. In addition to the limited number of surplus situations, the surplus characteristics exacerbate economic dimensioning of energy storage.

7. Conclusion

The results clearly indicate, that energy storage systems promise only a marginal potential of yield loss reductions in the near future. This applies to both, temporary and permanent network congestions. The main reasons are high generation costs for these applications caused by high technology costs and a small number of operational cycles for the examined time frame. From an economical perspective, alternative options such as network extension are more cost-effective.

As for the transmission grid level, the number of surplus situations and also surplus characteristics make it hard to find a sound business case for energy storage investments. Even under progressive assumptions the level of utilisation will not be favourable for additional energy storage in S-H and will most likely reduce with the continuing realization of grid expansion projects.

Against this background, merchant reasons do not justify the extension of storage for the investigated application. The identified costs cannot be covered by the potential revenues. Nevertheless, it has to be acknowledged that the analyses carried out above looked at historical scenarios on the distribution and a 2025 scenario on the transmission grid level. Future energy scenarios with higher shares of renewable energy sources and lower technology costs can create a different environment for energy storage applications. In addition to that, the analyses were conducted from a grid perspective and did not involve market simulations including balancing markets or an analysis of the specific benefits of an individual actor.

However, a potential implementation of energy storage can merely be reasoned economically, but rather from a system security perspective. Existing safety margins ensuring system security in Europe are challenged by an increasing level of renewable generation in the energy system. Energy storage systems enable the system operators to introduce new options for system operations in case of incidents and major disturbances. Given a demand for system security driven assets, energy storage systems could provide one technological solution, although needing specific subsidies.

8. References

[1] Leipziger Institut für Energie GmbH, „Vorbereitung und Begleitung der Erstellung des Erfahrungsberichts 2014 gemäß § 65 EEG – Vorhaben IIe Stromerzeugung aus Windenergie“ ,see https://www.bmwi.de/BMWi/Redaktion/PDF/XYZ/zwischenbericht-vorhaben-2e,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf, latest verification October 3, 2014.

[2] Bundesministerium für Wirtschaft und Energie, „Erneuerbare Energien im Jahr 2013 “, see http://www.bmwi.de/BMWi/Redaktion/PDF/A/agee-stat-bericht-ee-2013,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf, latest verification October 3, 2014.

[3] Ministerium für Energiewende, Landwirtschaft, Umwelt und ländliche Räume, „Abregelung von Strom aus Erneuerbaren Energien und daraus resultierende Entschädigungsansprüche in den Jahren 2010 bis 2013 “, see http://www.schleswig-holstein.de/Energie/DE/Strom/Einspeisemanagement/einspeisemanagement_node.html

[4] BDEW, „Anteil Erneuerbarer Energien am Stromverbrauch steigt im ersten Quartal auf Rekordwert von 27 Prozent “, see http://www.bdew.de/internet.nsf/id/20140509-pi-bdew-veroeffentlicht-erste-quartalszahlen-zu-erneuerbaren-energien-de, latest verification October 3, 2014.

[5] Pöyry, „POTENZIALUNTERSUCHUNG UND AUSBAUPROGNOSE ERNEUERBARER ENERGIEN IN SCHLESWIG-HOLSTEIN“, see http://www.schleswig-holstein.de/Energie/DE/Energiewende/Ziele/analyse1__blob=publicationFile.pdf, latest verification October 3, 2014.

[6] Ecofys, IWES, „Untersuchung Energiespeicher in Schleswig-Holstein “, see http://www.ecofys.com/files/files/ecofys-fraunhofer-iwes-2014-energiespeicher-schleswig-holstein-kurz.pdf, latest verification October 3, 2014.

[7] 50Hertz Transmission, Amprion, TenneT TSO, TransnetBW, „EEG-Anlagenstammdaten“, see http://www.netztransparenz.de/de/Anlagenstammdaten.htm, latest verification July 3, 2014.
[8] Schleswig-Holstein Netz AG, „Einspeisemanagement-Berichte der Schleswig-Holstein Netz AG“, see https://www.sh-netz.com/cps/rde/xchg/sh-netz/hs.xsl/2472.htm, latest verification October 3, 2014.
[9] Ecofys, „Einspeisemanagement in Schleswig-Holstein“, see http://www.ecofys.com/files/files/ecofys_2012_einspeisemanagement_in_schleswig-holstein.pdf, latest verification October 3, 2014.
[10] Ecofys „Abschätzung der Bedeutung des Einspeisemanagements nach § 11 EEG und § 13 Abs. 2 EnWG“, see http://www.ecofys.com/files/files/ecofys-2012-abschaetzung-einspeisemanagement.pdf, latest verification October 3, 2014.
[11] Schleswig-Holstein Netz AG, „Netzdaten: Lastverlauf als viertelstündige Leistungsmessung 2012 Netzgebiet Schleswig-Holstein, Veröffentlichung gemäß § 17 Abs. 2 Nr. 1 StromNZV“, see https://www.sh-netz.com/cps/rde/xchg/sh-netz/hs.xsl/395.htm, latest ver